CHAPTER 3. GEOLOGICAL SET-UP

3.1 Introduction

The calc-silicate rocks of the study area belong to the Lunavada Group, which constitutes one of the important Pre-Cambrian stratigraphic units of the SAMB in Gujarat. Lunavada Group is covering a roughly polygonal area of 10,000 sq.km, occupying parts of Sabarkantha and Panchmahal districts of Gujarat with its extension in SW part of Rajasthan (Merh, 1995). Out of a total of six formations of the Lunavada Group, parts of only Kadana Formation fall within Gujarat while rest of the formations occupy the areas of southern Rajasthan (Iqbaluddin, 1989).

The Lunavada Group, a wide basin for sediment deposition resulted during late to post-orogenic phase of the Aravalli Geological Cycle and is composed of a characteristic assemblage of thick accumulation of clastogenic metasediments along with the thin intercalations of chemogenic and biogenic rocks viz. phyllites, mica schists, chlorite schists, meta-siltstones, meta-semipelites, meta-protoquartzites along with the thin sheets of dolomitic limestone, petromict meta-conglomerate, manganiferous phyllite and phosphatic algal dolomite (Gupta et al., 1980,1992).

The youngest formation of the Lunavada Group,i.e. the 'Kadana Formation' which hosts the calc-silicate rocks under study covers the area from Devgadh Baria in the south, Lunavada in the west till Santrampur and Kadana to Dhudadia in the north (Gupta et al.,1997). It is composed of an alternating sequence of quartzite and meta-subgraywacke with partings of meta-semi-pelite and meta-siltstone (Iqbaluddin, 1989).

Quartzites and metapelites (biotite schists and garnet mica schists) are the associated rock types present within this area. The study area lying near Lunavada town, Mahisagar district can be traced with the help of Survey of India (SOI) topographic sheet number 46 E/12 which lies to the SE part of the Lunavada town within the latitude N 23º00'-23º09' and longitude E 73º35'-73º45'(Fig.3.1).

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* The Part of this chapter is based on our paper published:
Akolkar G, Joshi A U, Limaye M A and Deota B S 2018 Implication of Godhra granite emplacement on calc-silicate rocks of Lunavada Region, NE Gujarat; J. Geosci. Res. **3** 147-152.

The overall geological setting around the Lunavada Group reflects younger rocks which includes few infra-trappeans towards its south-east and along its west to south-western margin. Neo-Proterozoic plutonic intrusives (955 ± 20 Ma. Rb/Sr Method; Gopalan et al., 1979) known as the "Godhra granites" are lying along NW-SE trend, joining the Pandwa in the northwest to the Dhampur in the southeast.

This group has been divided into six formations viz., the Kalinjara, the Wagidora, the Bhawanpura, the Chandanwara, the Bhukia and the Kadana on the basis of strike persistence,lithological homogeneity and local relationship of superposition (Gupta et al., 1980, 1992).

The latest litho-stratigraphic succession of the Lunavada Group is proposed by earlier workers viz, Iqbaluddin (1989) and (Gupta et al.,1980,1992).

The author follows the litho-stratigraphy proposed by (Gupta et al.,1980,1992), (Table 3.1) as it is modified in terms of lithology observed and the changes in the nomenclature of two formations viz. the basal 'Wardia Formation' and the 'Nahali Formation' overlying it, which were nomenclated by Iqbaluddin (1989) and later changed to 'Kalinjara Formation' and Wagidora Formation' respectively.

The principal rock-types of this group encountered are phyllite, feldspathic mica schist, metasubgraywacke with subordinate quartzite and dolomite, pebble conglomerate and quartzite,quartz-chlorite-sericite schist and meta-protoquartzite, quartz arenite, metasubgraywacke, metapelites with intercalations of calc-silicate rocks, metasiltstone. Here, basement rocks are not exposed and the entire sequence is intruded by 'Godhra granite'.

The calc-silicates reside within the host rocks, i.e. metapelites in low-lying areas and are surrounded by tightly folded quartzitic ridges.

Prominent ridges of quartzites are on account of their high resistance to weathering, due to which undulating topography is generated. Occurrence of calc-silicates within metapelites is sporadic. They occur as discontinuous lenses and bands with varying widths and lengths.

Regional scale folds i.e. F_1, F_2 and F_3 have their impressions over the rocks present in and around Lunavada which are formed on account of D_1-D_3 deformational episodes.

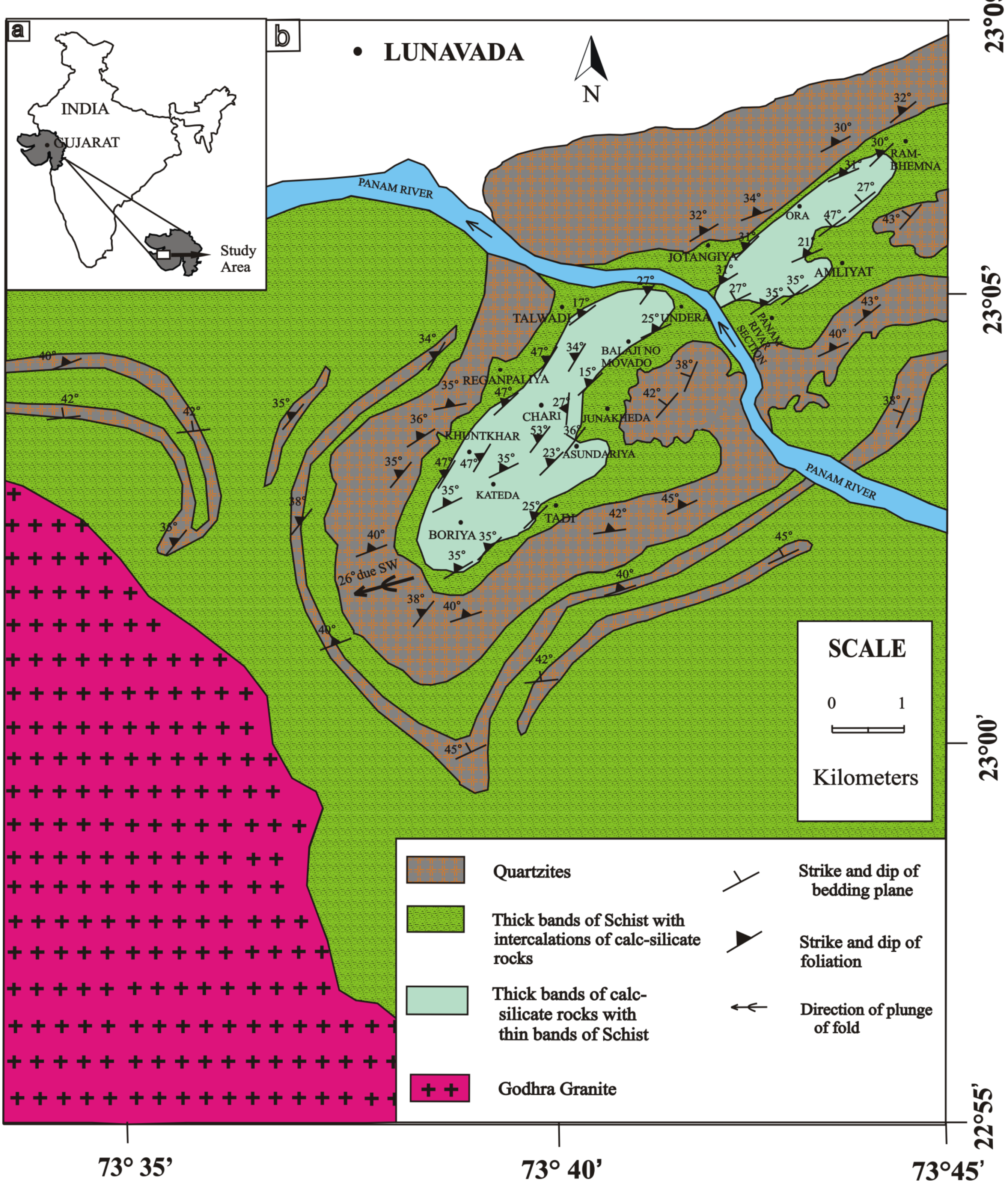

Figure 3.1: Geological map of the study area, modified after Mamtani (1998).

Table 3.1: Lithostratigraphy of the Lunavada Group (modified after Gupta et al., 1980, 1992)

Cretaceous to Eocene	DECCAN TRAPS		
	--Unconformity---		
Neo-Proterozoic	GODHRA GRANITE		
	--Unconformity---		
Meso-Proterozoic	LUNAVADA GROUP	**Kadana Formation**	**Quartz arenite, metasubgraywacke, metapelites with intercalations of calc-silicate rocks, metasiltstone**
		Bhukia Formation	Metaprotoquartzite, metasubgraywacke, metasiltstone, quartz-chlorite-sericite schist and quartzite
		Chandanwara Formation	Metasubgraywacke, metaprotoquartzite, quartz-chlorite schist and quartzite
		Bhawanpura Formation	Quartz-chlorite-sericite schist and metaprotoquartzite with minor bands of metasubgraywacke
		Wagidora Formation	Metasubgraywacke, Mica schist with intercalated graywacke, pebble conglomerate and quartzite
		Kalinjara Formation	Phyllite, Feldspathised mica schist, metasubgraywacke with subordinate quartzite and dolomite
Base not seen			

F_1 and F_2 folds are coaxial with NE-SW axial trend, while F_3 fold have NW-SE trend and D_3 is coeval with the granite emplacement (Mamtani et al., 2001; Mamtani and Greiling 2005; Mamtani et al., 2002; Sen and Mamtani 2006).Several NW-SE trending axial planer slippages have also been recorded with the last phase of deformation (Mamtani et al., 1999a; Joshi et al., 2016).

Deformation led to certain metamorphic changes within rocks which are observed in the form of their altered mineralogy as well as textures.

One or more deformational events affected various parts of the area and changed overall outcrop patterns at regional scale. This is quite obvious from the satellite imagery of the study area (Fig. 3.2).

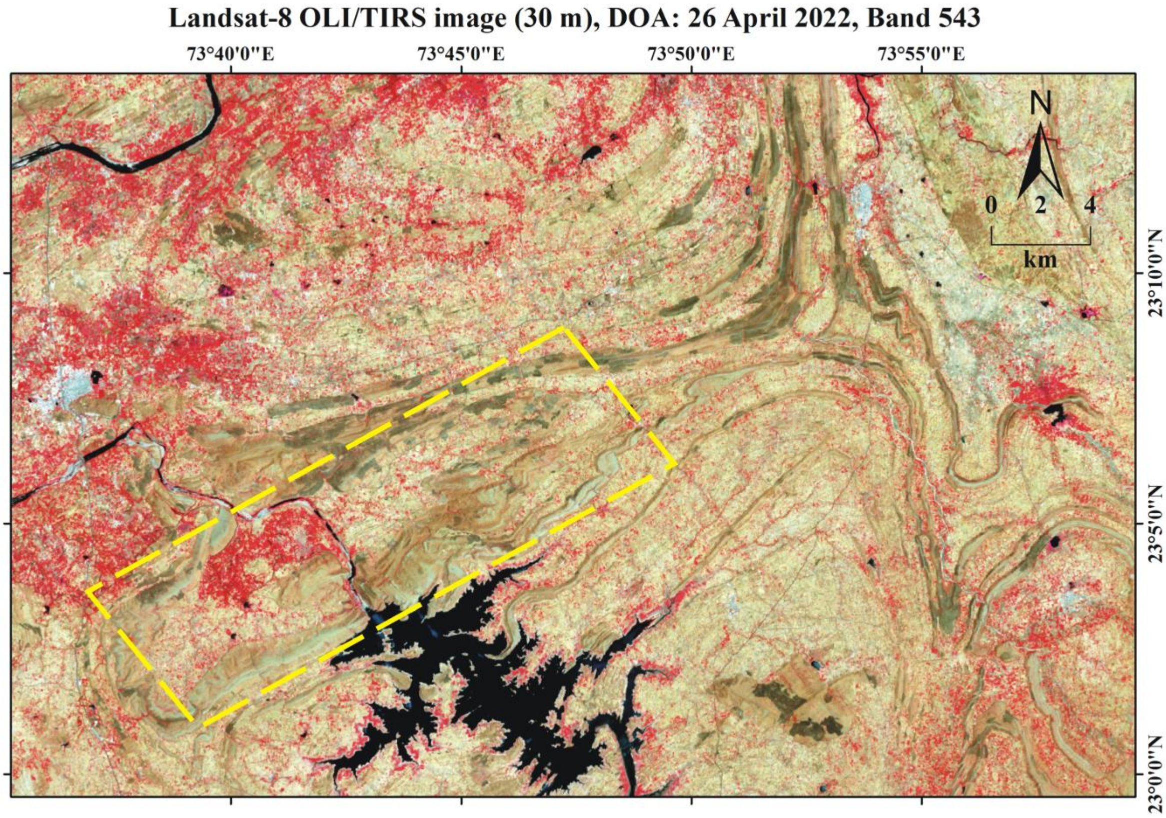

Figure 3.2: Satellite imagery (False Colour Composite) of the part of the area lying southeast to the Lunavada town (Toposheet no.46E/12). Rectangle with dashed lines indicates the study area.

3.2 Field characteristics of calc-silicates and other associated rock types

3.2.1 Calc - silicate rocks

Megascopic characteristics of near about 40 calc-silicate rock samples had been observed within the study area. These calc-silicates possess fine to medium-grained size and are light to dark grey in colour. At most of the places star shaped or unoriented amphibole needles have been noticed (Fig 3.3a).Occasionally, marginal orientation of amphibole needles is also seen, mainly in those calc-silicates which are in close contact with metapelites (Akolkar et al., 2018).

The presence of maculose structure is obvious due to the heat supplied by the intrusive activity of granitic pluton lying nearby (Fig 3.3b). At few places calc-silicates are found to have compositional bandings also formed probably due to metamorphic differentiation process (Fig.3.3c).

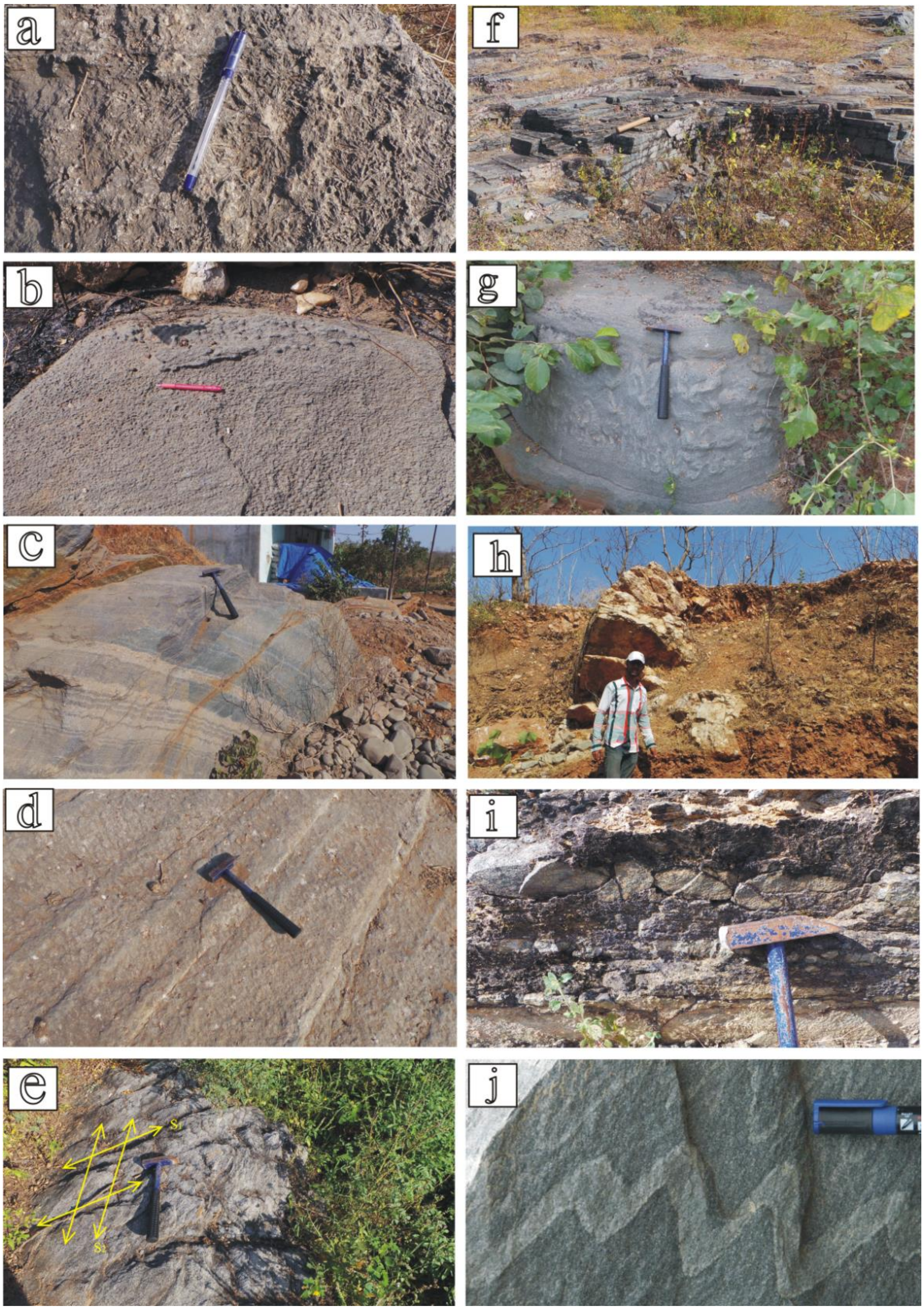

Figure 3.3: Field photograph showing, (a) Unoriented/star shaped amphibole needles within calc-silicate rock, Loc. Jotangiya; (b) Maculose structure over calc-silicate surface, Loc. Ora; (c) Compositional bandings, Loc. Amliyat; (d) Differential weathering of calc-silicates, Loc. Panam river section; (e) Development of S_1 and S_2 foliations within calc-silicate, Loc. Talwadi; (f) Two sets of joints within calc-silicates, Loc. Junakheda; (g) Structure like convolute bedding, Loc. Balaji No Muvada (h) Pegmatite vein discordant to calc-silicate rocks; Loc. Ora (i) Boudinage of quartzite within calc-silicate rock,Loc. Junakheda (j) Folded quartz vein within calc-silicate, Loc. Chari.

Differential weathering of these rocks has generated uneven surfaces i.e. resistant parts stand up like ridges while non-resistant part is planar comparatively (Fig.3.3d). Foliations as well as well-developed two sets of joints are the other features observed (Fig.3.3e and Fig.3.3f).Rarely, structures like convolute bedding, the presence of discordant granite-pegmatite veins observed within these rocks (Fig.3.3g and Fig.3.3h). At Junakheda, located at in the southern part of the study area, 'boudinage structure'i.e. a layer parallel extensional structure can be seen to be developed within calc-silicate rocks (Fig.3.3i). This is getting formed here because the rocks like calc-silicates which are less competent embed the more competent rock like quartzites within them. At village Chari, a peculiar feature with folded quartz vein embedded within the calc-silicate rock has been noticed (Fig 3.3j).

Megascopically, only actinolite needles can be seen over the rock surfaces having a length from 0.2 to 0.5 cm but near Jotangiya village located to the NE of the study area differential weathering led to the removal of actinolite needles which must be having a length from 2 to 8 cm as revealed by the voids generated here.

3.2.2 Quartzites

Monotonous ridges of quartzites can be seen throughout the study area. These quartzites occur as hard, massive, compact rocks. They are mainly grey coloured, fine to medium grained and are homogeneous in nature. These rocks are highly jointed and three sets of joints are clearly visible (Fig.3.4a). At some places massive, brownish yellow or buff coloured quartzites can also be seen (Fig.3.4b).Apart from individual ridges of quartzites, they can be observed in the form of intercalations with metapelites mainly in well sections. The height of the ridges varies from 100-150m within the study area.

The quartzites exposed here have almost 8-10% of biotite, hence can be termed as 'Micaceous quartzites. Numerous quartz veins having variable trends can be seen cutting these quartzites across. Conchoidal surfaces are common. The plumose markings developed can also be seen over the surfaces of quartzites at few places (Fig.3.4c). Weathering led to the reddish brown surfaces of quartzites due to the leaching of iron oxide. (Fig.3.4d)

According to (Mamtani, 1998), a complex fold interference pattern is indicated by sinuous and complex trends of quartzite ridges. It is on account of the superposition of at least three folding phases. Limbs of this overturned fold can be seen to be coming closer at the northeastern extremity of the study area whereas the western part of the area is dilated and exhibit swollen outcrop-like pattern.

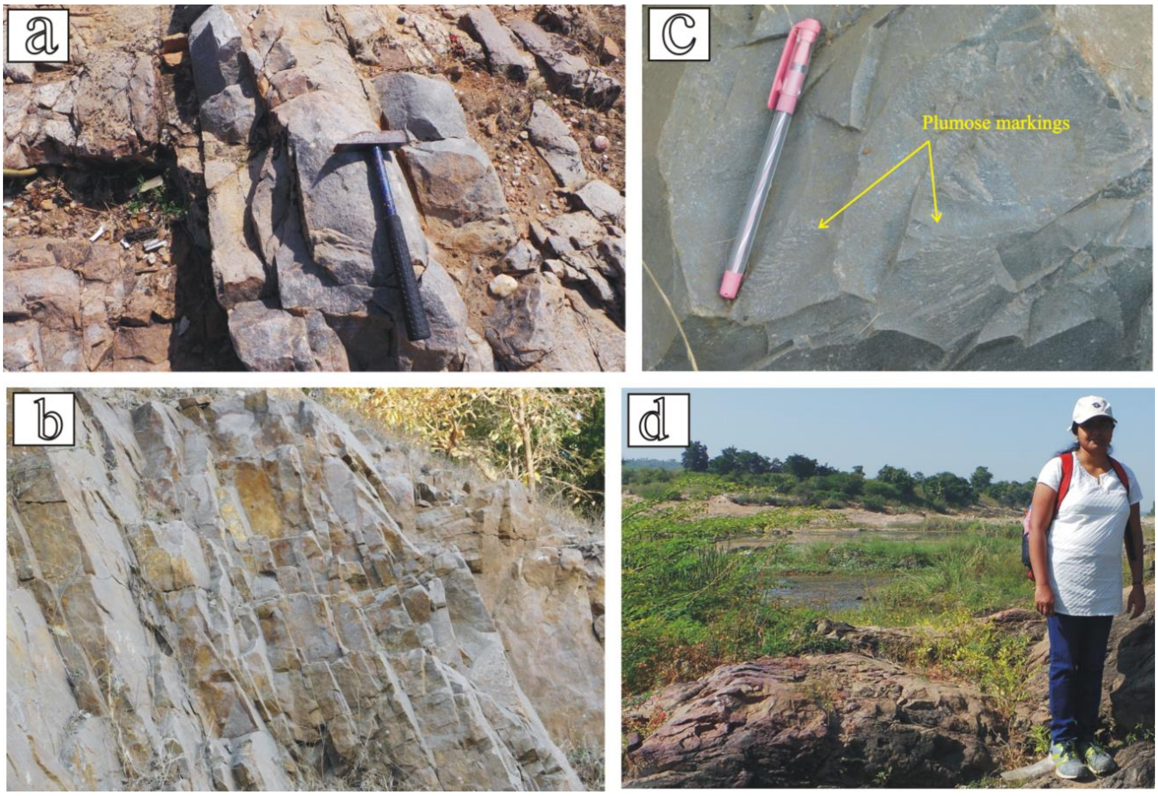

Figure 3.4: Field photograph showing,(a) Jointed quartzite, Loc. Panchmuva; (b) Massive, buff coloured quartzites, Loc. Tadi; (c) Plumose markings in quartzite, Loc. Hoselav; (d) Reddish brown surfaces of quartzite, Loc. Chandsar.

These quartzites exhibit E-W to NW-SE strike with variable dip amounts. Primary sedimentary structures are seen to be less preserved and may be obscured due to medium grade of regional metamorphism in the area i.e. lower amphibolite facies of metamorphism as recorded by (Mamtani, 1998). A regional scale overturned type of fold of quartzites surrounds the study area. The regional scale anticline has an E-W trend which is plunging 26° due SW.

3.2.3 Metapelites

In the study area limited outcrops of metapelites are encountered. Although they are sparsely present on the surface as are covered by soil and alluvium, their occurrence can be very well noted in well sections in the form of intercalations with quartzites (Fig.3.5a) and sometimes along the road, nala or river sections due to which determination of orientations of these lithologies is facilitated. As within the study area, surficial exposures of these rocks are scanty, characteristics of metapelites from nearby places around the study area have also been discussed here as those rocks are representative of metapelites of Kadana Formation as a whole. In the Mahi river section, located nearly 18 km northwest of the study area, good intercalations of quartzites and metapelites can be seen (Fig.3.5b).The thickness of the entire section is approximately 15 feet. Here, chlorite schist is present. As we come closer to the study area i.e towards the south, exposures of biotite schist are observed near village Junakheda. The schistose structure is well defined in these rocks with alternate the layering of light and dark minerals (Fig.3.5c).The strike of this outcrop is NW-SE, dipping 75° due NE.

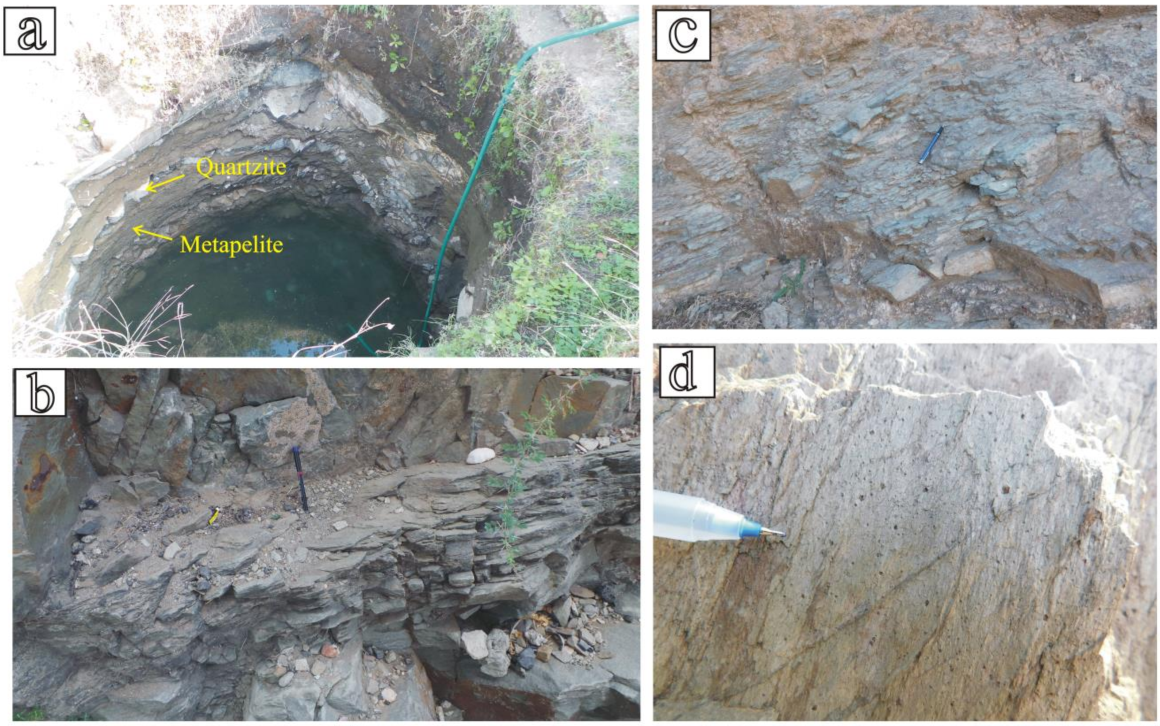

Figure 3.5: Field photograph showing,(a) Well section having intercalations of metapelite and quartzite, Loc. Boriya; (b) Mahi river section showing intercalated sequence of chlorite schist and quartzite; (c) Outcrop of biotite schist, Loc. Junakheda ; (d) Garnet mica schist, Loc near Labhi village.

Towards further south, near Labhi and Shekhpur villages good exposures of garnet mica schist can be seen. The garnet mica schist observed here, has large dark red porphyroblasts of garnet with the presence of well-developed schistosity (Fig.3.5d). These schists show garnet crystals with size ranging from <1 mm upto 3mm.

An appearance of chlorite in the schist in northernmost part of study area while appearance of biotite in the middle part i.e. within the study area and the appearance of garnet in the southernmost part of study area points towards the increase in grade of metamorphism from north to south.

3.2.4 Granites

The Godhra granite pluton which is intrusive to the Lunavada Group lies towards the west of the study area at an approximate distance of 7 Km as a linear stretch with the NW-SE trend extending beyond the Champaner Group and having variable widths. As it has its impact on the rocks of the study area in the form of the development of disorientation of amphibole needles and maculose structure as well as it plays an important role in the process of metamorphism, the author finds it rational to give its detailed description although there is an absence of any granite exposure within study area.

The granites exposed here are in the form of monadnocks, hills, bosses and tors (Fig.3.6a). The granites are fine to coarse-grained, leucocratic to mesocratic (pink to light grey coloured) and often show the porphyritic nature where large feldspar (mostly potash feldspar) phenocrysts are appeared to be lying within mosaic of quartz, biotite and accessory minerals. The following two varieties of granites have been identified (a) fine to medium-grained grey granite and (b) coarse-grained pink granite

3.2.4.1 Fine grained grey granite

The fine to medium-grained grey granite is dominantly exposed as bosses in the western parts of the study area near Guneli and Erandana Muvada villages. The granites are mesocratic, inequigranular and massive. The average height of granitic bodies present here is 2.5 m. In this rock phenocrysts of plagioclase feldspar and biotite are oriented in a single direction.Xenoliths of schist rock are entrapped within this granite and are also having the same orientation as that of phenocrysts of feldspar and biotite (Fig.3.6b). This feature points towards the deformation of granite. At some places biotite segregation has also been found within these rocks. The contact between granite and quartzite is observed at the northeast of Kothamba village which shows the intrusive nature of granite (Fig.3.6c).

3.2.4.2 Coarse grained pink granite

The coarse-grained, pink-coloured, potash granites dominantly occur 17 km southward of Lunawada town at Palikhanda village. Here, the granitic body is present in the form of stock or boss. The mineralogical composition of granite includes quartz, potash feldspar, muscovite, biotite mica and tourmaline predominantly and rarely, garnet. These granites are porphyritic and show tabular phenocrysts of K-feldspar mostly developed in the groundmass of quartz, muscovite, biotite and accessory minerals (Fig.3.6d).

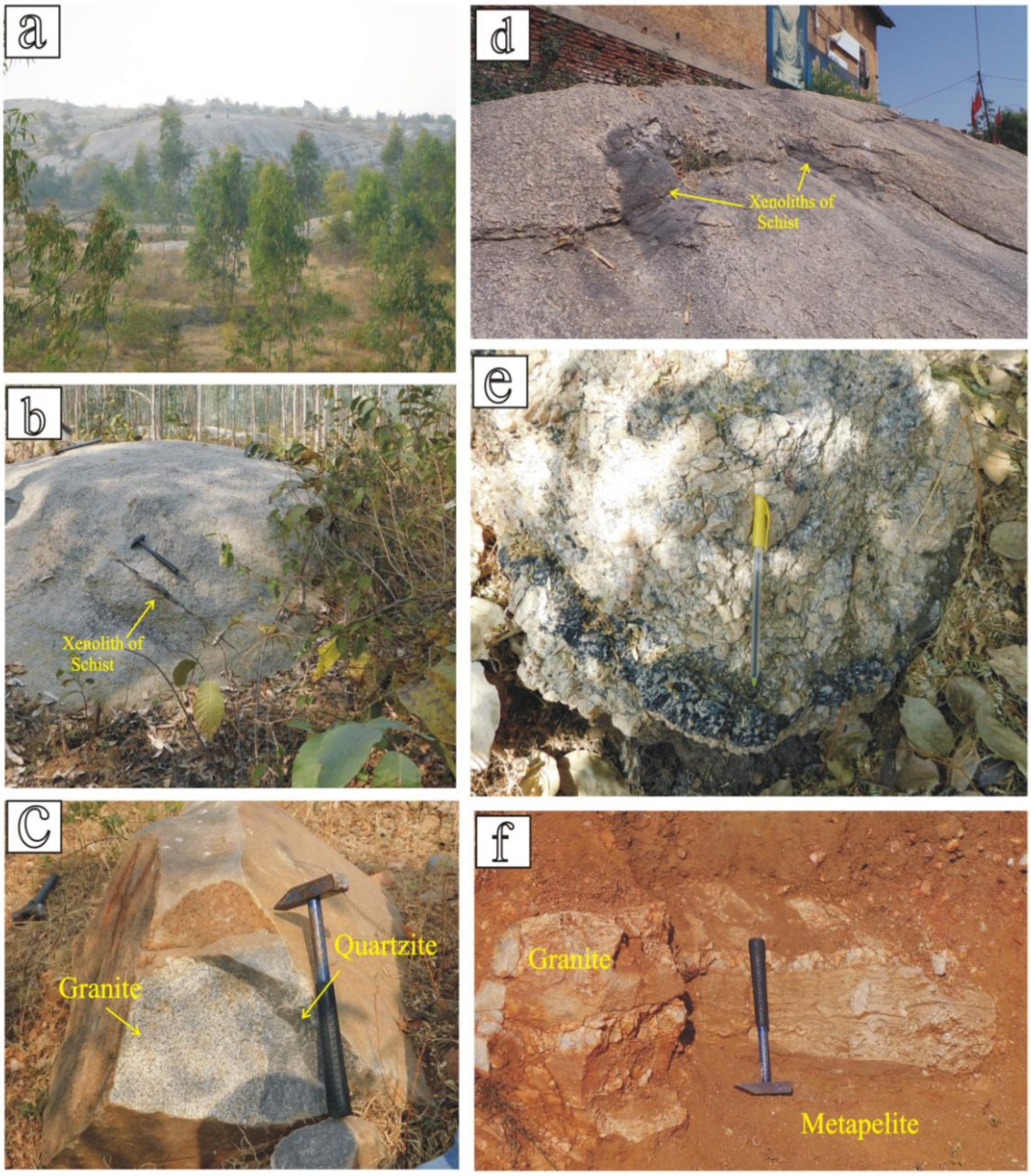

Figure 3.6: Field photograph showing, (a) Panoramic view of granite country, Loc. Erandana Muvada; (b) Fine grained grey coloured granite having xenolith of schist, Loc. Guneli; (c) Granite- quartzite contact, Loc. Kothamba; (d) Coarse grained pink granite having xenoliths of schist, Loc. Palikhanda; (e) Pegmatite within granite with segregated tourmaline crystals, Loc. Hosselav; (f) Granite –Metapelite contact, Loc. Jhaidi.

The average size of phenocrysts is ranging from 1cm to 5cm. The pink colour of the coarse-grained granite is attributed to the dominance of K-feldspar as phenocrysts and in the groundmass. These phenocrysts are elongated and their strike coincides with the strike of granitic emplacement. Entrapment of schist can be seen within this granite. Such schist xenoliths are a common feature found here, which indicates rapid emplacement of the pluton. Similarly, this granitic body is sheared at many places which also points towards rapid emplacement.

Near Village Hathivan, located at the west of study area, quartz or pegmatite veins can be seen passing through coarse to medium-grained pink granite. Here, in the nearby area some garnet-bearing granites also occur. The average grain size of garnet is about 3 mm. Near Hosselav village pegmatite veins show high tourmaline concentration (Fig.3.6e) pointing towards high chances of 'Boron metasomatism' of surrounding metasediments.

Near village Jhaidi, granite and schist contact can be seen (Fig.3.6f). Such features along with the entrapped xenoliths of metasediments within granite, the presence of minerals with high alumina content like muscovite, biotite and garnet as well as their leucocratic nature are the characteristics of the 'S' type of granite (Gill, 2010).

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